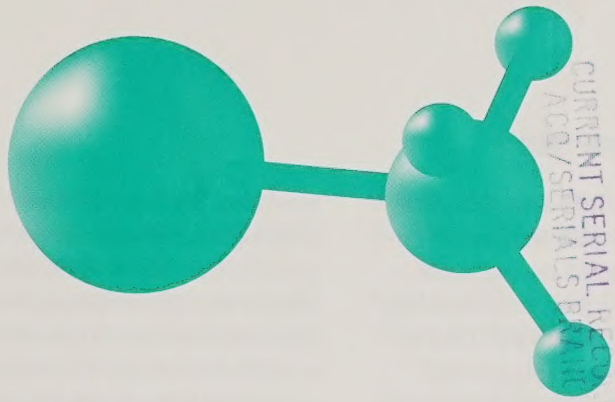
Methyl Bromide *Alternatives*



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This issue and all back issues of the *Methyl Bromide Alternatives* newsletter are now available on the Internet at **<http://www.ars.usda.gov/is/np/mba/mebrhp.htm>**.
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This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

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A Summary of USDA-ARS SCA Project: Field Scale Demonstration/Validation Studies of Alternatives to Methyl Bromide in Plastic Mulch Culture in Florida

Background

Florida tomato, pepper, strawberry, and eggplant growers have almost exclusively relied upon methyl bromide for the last 35 years to resolve most of their soilborne pest- and disease-control problems. Methyl bromide, added to the Class I category of ozone-depleting substances, is required to be phased out of production internationally under provisions of the Montreal Protocol. U.S. production of methyl bromide has already been reduced from a 1991 baseline by 70 percent in 2003, and will be totally phased out in 2005. Florida accounts for about 30 percent of preplant methyl bromide use nationally. Economic analyses conducted in 1995 for Florida tomato, pepper, and strawberry production predicted significant losses in vegetable crop acreage, per acre production, and market share to international competitors with the adoption of pest-control and crop-management alternatives to methyl bromide soil fumigation.

Based on initial chemical performance studies during the period 1994 to 1996, Telone C-17, in combination with the herbicide Pebulate (Tillam), was identified as providing a near-equivalent, best alternative to methyl bromide for nematode, disease, and nutsedge control in Florida fresh-market tomato production. This treatment also served as the model for future field evaluation efforts in other crops, such as strawberry and pepper.

In 1995, a small group of University of Florida scientists assembled to discuss, organize, and optimize future alternatives to methyl bromide research efforts within the State, as well as to draft a long-term, 5-year research project proposal for possible USDA-ARS funding. Annual funding was secured from the USDA during the period of 1996 to 2001 in amounts ranging from $220,500 to $243,750. It was used to initiate field-scale demonstration/validation studies at multiple sites within the major crop producing regions of Florida and to support the conduct of small-plot field research trials at various locations statewide.

Over $1 million has been allocated to researchers in Florida to investigate the efficacy of various alternatives to methyl bromide in plastic mulch culture production in Florida. The studies reviewed here were conducted in various timeframes from 1996 to 2001.

Different substances and production systems to control weeds, pests, and diseases were investigated—predictably, with varying results. Alternative fumigants, herbicides, biorationals, application techniques, resistant plants, solarization, cover cropping, organic amendments, flooding, and crop rotation were all examined by a number of scientists.

Both large-scale field demonstration studies and small-plot field research trials were conducted during these years. Overall, 54 projects, involving 21 University of Florida and USDA scientists, were separately funded during the 5-year granting period. A general summary, based upon the report prepared by Joseph Noling of the University of Florida, of these studies follows.

Tomato Large-Scale Field Demonstration Trials

Since the fall 1996 cropping season, more than 40 U.S. Department of Agriculture-funded, large-scale, field-demonstration validation trials have been performed in west, west central, south, and southwest Florida tomato, strawberry, and pepper fields. Much of the research conducted between 1996 and 1998 focused on in-row applications of Telone C-17 or Telone C-35. Telone label requirements, however, call for personal protective equipment for field workers during application. For this reason, more recent research efforts have focused on evaluations of broadcast applications of Telone at least 5 days in advance of bedding. The most recent trials compared Telone II (15 to 18 gallons/acre), Telone C-17 (35 gallons/acre), or Telone C-35 (26 gallons/acre) applied broadcast or in-row, in combination with other fumigants and herbicides Tillam (2 to 4 pounds/acre), Devrinol (2 to 4 pounds/acre), and/or Treflan (0.3 to 0.75 pounds/acre) to that of methyl bromide (67/33; 350 pounds/acre) for weed, disease, and nematode control, and for tomato and pepper yield response.

The large-scale, field-demonstration trials were also used to determine whether the newly developed Yetter deep-placement coulter injection system for Telone products could improve pest control efficacy and crop yield response, compared to results of previous studies investigating broadcast application systems that relied upon pre-disking, simple straight, or forward-swept injection chisels, followed by a roller to seal chisel holes in surface soil. In some of the broadcast Telone trials, an additional application of chloropicrin (100 to 200 pounds/acre) was included as a separate soil injection treatment at the time of bedding. All studies were conducted in grower fields with plot sizes ranging from 1 to 13 acres.

In researching tomatoes, these large-scale, field-demonstration studies revealed that both product formulation and method of application were significant determinants of crop yield response compared to methyl bromide. Generally, and regardless of application method, Telone C-35 provided greater tomato yields than Telone C-17. Similarly, in-row applications of Telone C-17 or Telone C-35 were superior to broadcast applications. Tomato yields were increased 15.2 percent and 6.6 percent with in-row applications of Telone C-17 or Telone C-35, respectively, when compared to their corresponding broadcast treatment. According to Noling, higher yields obtained with in-row applications were likely a result of improved soil fumigation efficiency. There was more uniform fumigant dispersion, distribution, and dissipation under the raised, plastic mulch-covered planting beds compared to bare ground, broadcast applications made to undisturbed soil.

In-row application of Telone C-17 or Telone C-35 may have shown improved tomato yields, but they were not always as effective as methyl bromide. When field demonstration results were examined, only 7 of 22 trials using in-row application of Telone C-17 + Tillam produced higher yields than those of methyl bromide. Average tomato yield losses for in-row application of Telone C-17 + Tillam was 4 percent with a standard deviation of ± 2 percent. Comparatively, yield responses varied from a potential loss of 8.2 percent to an increase of 0.2 percent.

Overall, field-demonstration studies of broadcast Telone C-17 treatment have not produced the same results as the in-row Telone C-17 treatment. For example, two large-scale, field-demonstration trials with broadcast applications of Telone C-17 (35 gallons/acre) have produced tomato yields that average 19.2 percent less than those obtained with methyl bromide.

On the other hand, in three of eight demonstration trials of in-row applications of Telone C-35 + Tillam, higher yields of tomatoes were produced than with methyl bromide. On average, however, tomato yields were 0.4 percent ± 5 percent higher with Telone C-35 in-row application and Tillam treatment with methyl bromide. Compared to methyl bromide, Telone C-35 in-row treatment exhibited a potential loss of 12.25 percent to an increased yield of 13 percent. Broadcast Telone C-35 treatment indicated an average yield reduction of 6.2 percent with a standard error of ± 3.9 percent, compared to the yield with methyl bromide. Research yields project a range from a potential loss of 15.7 percent to an increased yield of 3.3 percent. “The combined results of these trials suggest that if broadcast applications of Telone C-35 have to be exclusively relied upon to avoid regulatory issues regarding workers’ needs for personal protection equipment, then marginal losses in crop yield of 6 to 7 percent will be incurred, and some crop yield variability from season to season and field to field,” says Noling.

Two trials to evaluate broadcast applications of Telone products, combined with and followed by in-row applications of chloropicrin (100 to 200 pounds/acre) at the time beds are formed, show tomato yields on average to be 2.1 percent greater than yields obtained with methyl bromide. This suggests that improvements to crop yield potential and response consistency relative to methyl bromide can be achieved with broadcast applications of Telone treatments if additional chloropicrin can be applied at the time of bedding. Yield benefits also appear to accrue as a result of improved pest control efficacy.

Pest Control Efficacy in Tomato

Nematode control has generally been good to excellent with all broadcast treatments of Telone products. The superiority of the broadcast Yetter coulter rig was clearly demonstrated in some trials with Telone C-35, providing better root-knot nematode control than that obtained with methyl bromide, presumably due to the deeper, 12-inch placement of Telone C-35 into previously undisturbed soil. The addition of chloropicrin either in the formulation with Telone or as a separate treatment prior to bedding, resulted in disease control that was invariably improved, but not always to the level of methyl bromide. An increase in disease incidence was observed when Telone products were broadcast applied, and not immediately followed by additional chloropicrin to the bed at the time of bed construction. "This suggests that choloropicrin escaping from untarped soil can significantly reduce overall disease control. It should also be noted that along with the loss of disease control, there is also a reduction in fruit production in some trials," says Noling.

In some trials, reduced efficacy was observed during the spring when hot and dryer soil conditions prevailed, which presumably favored more rapid escape of chloropicrin. Overall, it appears that the cropping season itself may not be as important as prevailing environmental conditions, and that additional chloropicrin in the bed at the time of bed formation will in many cases improve disease control efficacy.

Tillam, when applied alone in previous tomato demonstration trials, has shown less than ideal performance when there was a broad spectrum of weed species in the field. In those studies, various grasses, black nightshade, ragweed, pigweed, and purslane were oftentimes not effectively controlled. As a result of these previous findings, new research efforts targeted the evaluation and performance of various herbicides applied either alone, or in tank mix combinations, for overall weed control in both tomato and pepper. For example, tank mixing Devrinol or Treflan with Tillam typically broadened the weed control spectrum in most cases, improving control of some weeds not controlled by Tillam alone. Treflan was especially effective against crabgrass, and it provided improved pigweed control in at least one field demonstration location. In some trials, combination of the three herbicides—Tillam, Devrinol, and Treflan—usually improved the spectrum of weed control efficacy in tomato, such that it was equivalent to that of methyl bromide. Tillam efficacy was also influenced by the timing of application. Due to stunted tomato plant growth in some trials, it may be prudent to consider application of Tillam 7 to 10 days in advance of bed formation to minimize, though not eliminate, the risk of herbicide injury on tomato or other crops. "Some cases of severe stunting," says James Gilreath, of the University of Florida's Gulf Coast Research and Education Center, "are due to improper incorporation or doubling of the application rate."

Large-Scale, Field-Demonstration Trials for Strawberry

Alternatives to methyl bromide research efforts at University of Florida research and education centers in Dover, Quincy, and Gainesville were initiated in 1995 and have continued to the present. The primary focus of this research has been to evaluate cultural and chemical alternatives to methyl bromide soil fumigation within Florida strawberry production. The early USDA/ARS-funded studies at Dover clearly demonstrated that strawberry productivity in Florida could be substantially reduced (50 to 70 percent) by growing plants in soil that had not been fumigated prior to planting—even in the absence of lethal pathogens. The results of chemical trials clearly demonstrated significant increases in strawberry yields over those of the untreated control and equivalent to, if not higher than, those obtained with methyl bromide following use of chloropicrin (300 pounds/acre); Telone C-17 (35 gallons/acre); and, in some trials, with chloropicrin (300 pounds/acre) plus metam sodium (75 gallons/acre); or metham sodium (75 gallons/acre) plus Telone II (12 gallons/acre). In some of the trials, strawberry yield responses were proportional to the amount of chloropicrin actually applied, strongly suggesting the importance of other undefined soil pathogens as primary yield determining factors and of using a fumigant with excellent fungicidal activity. It was also determined that because chloropicrin was such a poor nematicide, another fumigant that could broaden the spectrum of soil pest control activity to include nematodes was needed. As a result, Telone C-17 or Telone C-35 was determined to be the most promising,

currently registered, fumigant alternative to methyl bromide for Florida strawberry. There was also grower concern that too much chloropicrin would confer an undesirable increase in vegetative growth response, further confirming the need to target Telone C-17 and Telone C-35 for evaluation in advance trials.

Since 1997, 13 USDA-funded, large-scale, field-demonstration trials have been performed in the Plant City, Florida, area comparing Telone C-17 (35 gallons/acre) or Telone C-35 (26 gallons/acre) applied in-row or broadcast, in combination with the herbicide Devrinol (4 pounds/acre) to that of methyl bromide (67/33; 350 pounds/acre) for weed disease, nematode control, and strawberry yield response. Grower fumigation and bedding equipment were used for all in-row applications of Telone C-17 or Telone C-35. Devrinol, when it was used for weed control, was applied as a surface spray prior to soil fumigation and incorporated 2 to 4 inches deep with a rolling cultivator. Most fields had no prior history of severe pest pressures. At three of the grower sites, Telone C-17 or Telone C-35 has been repeatedly evaluated in the same field location for as many as 3 years to examine long-term impacts of repeated Telone use.

At none of the field demonstration sites, during the research period (1997 to 1999), were substantial differences in the incidence of dead or declining plants per row ever observed between in-row applications of Telone C-17 (35 gallons/acre) and methyl bromide. In general, no differences in weed control were observed at any time between Telone C-17, plus Devrinol and methyl bromide treatment. Overall, strawberry plant growth obtained with the Telone C-17 or Telone C-35, plus Devrinol in-row treatments, was comparable to that of methyl bromide yield, particularly at season's end in March.

The Telone label requirement for a full spray suit, rubber gloves, boots, and a full-face respirator by all personnel in the field at the time of application prompted a new research focus in 1999 towards evaluation of broadcast, rather than in-row, treatments of Telone C-35 (26 gallons/acre) applied prior to bedding to minimize personnel protective equipment requirements. Seven field-demonstration trials evaluating broadcast applications of Telone C-35 were conducted from 1999 to 2001. Broadcast applications, in these trials, were made with either a deep-placement Yetter coulter system (courtesy of Mirusso Fumigation and Equipment, Delray Beach, FL), or with a 12-inch, forward-swept chisel plow followed by a rolling operation to provide for a seal of surface soil (courtesy of Hy-Yield Bromine, Plant City, FL). Devrinol (4 pounds a.i/acre), when it was used for weed control, was applied as a surface spray prior to soil fumigation and incorporated 2 to 4 inches deep with a rolling cultivator.

None of the three demonstration sites in 1999 or four sites in 2001 showed substantial differences in the incidence of dead or declining plants between broadcast treatments of Telone C-35 and methyl bromide. At two sites from 2000 to 2001, where a herbicide was not applied prior to bedding, weed densities were 2 to 4 times higher with broadcast or in-row applications of Telone C-35 compared to areas treated with methyl bromide. At three of the sites, significant differences in plant size were observed between Telone C-35 and methyl bromide.

Based on overall results of the seven large-scale field demonstration trials conducted from 1999 to 2001, strawberry plant growth and vigor with broadcast treatments of Telone C-35 (26 gallons/acre) were generally observed to be comparable to that of methyl bromide. Yield records were incomplete or not provided by grower cooperators, so a more comprehensive assessment of yield impacts is not possible. However, based on empirical observations during the growing season of these trials, strawberry yields are not likely to be substantially reduced with either Telone C-17 or Telone C-35, applied either broadcast or in-row, as long as a supplemental preplant herbicide is applied and incorporated properly. A sufficient waiting period before bedding and transplanting must be observed after fumigant application. As in tomato, combinations of broadcast applications of Telone C-35, followed by additional chloropicrin at the time of bedding, may also serve to improve strawberry yield and response consistency. This aspect is a focus of current research.

Field-scale demonstration trials have proceeded in strawberry under the presumption that some U.S. EPA regulatory change in requirement for personal protection equipment and possible reduction in buffer zones, which currently restrict application of Telone products within 300 feet of any occupied dwelling, will occur in the near future in Florida. It should be recognized, if regulatory changes in personal protection equipment and/or buffer zone restrictions do not occur in Florida, strawberry growers will either have to move to new production sites where buffers are not an issue, or accept significant yield losses following use of other pest- and crop-management tactics.

Long-Term Cropping System Studies in Tomato

A 3-year study was conducted at the Gulf Coast Research and Education Center in Bradenton, Florida, from the

fall of 1998 to the spring of 2001 to examine long-term impacts of repeated use of certain chemical and nonchemical treatments and cropping systems on pest population levels and multicrop productivity. The study compared standard methyl bromide soil fumigation against the best chemical alternative (Telone C-17 used in combination with Tillam), and the best nonchemical alternative (soil solarization), for soilborne pest control and crop response in both fall tomatoes and spring double-cropped cucumbers over multiple years on the same site. Tillam (4 pounds a.i./acre) was applied broadcast, preplant, then Telone C-17 (35 gallons/acre) was applied through three chisels to the soil in 8-inch raised beds during the summers of 1998, 1999, and 2000. Methyl bromide (350 pounds/acre of 67/33 percent) was applied at the same time and in a similar fashion. Solarization proceeded for 7 weeks during the summer of 1998 and 8 weeks during 1999 and 2000. Seven days before transplanting tomato, all solarization and nontreated control plots were sprayed with paraquat (0.5 pounds/acre) to eliminate existing weeds. Six-week-old Solamar tomato plants were transplanted in mid-September of each year. Tomato plants and weeds were sprayed twice with paraquat after the last tomato harvest in the fall and before planting spring cucumbers.

On nutsedge, both fumigants and soil solarization reduced nutsedge compared to the nontreated control throughout the season, and there were no statistically significant differences in nutsedge plant numbers between either of the fumigants or between the fumigants and soil solarization. This is due in large part to the early dessication of nutsedge in solarization plots.

Root-knot nematode populations were low in the test area soil at the beginning of the experiment in 1998, but this increased greatly in the nontreated control plots in 1999 and declined significantly in 2000. Root-knot populations remained low and fairly stable over the 3 years during the tomato crop with methyl bromide and Telone C-17. There was an increase in root-knot nematode population from 1998 to 1999 with soil solarization, but a slight decline occurred in 2000. In each of the 3 years, tomato plants in the soil solarization plots and the nontreated controls displayed the most severe galling of roots. Plants in soil treated with methyl bromide displayed no gall formation in the first year, but galling increased over the next 2 years. Results were intermediate with Telone C-17 during the first year, similar to methyl bromide the second year, and the least of all the treatments during the third year. Both fumigants were superior to either soil solarization or the nontreated control in reduction in the incidence of *Fusarium* wilt of tomato.

Tomato production generally declined each of the 3 years from the levels in the first year. In the 1998 season, methyl bromide and Telone C-17 + Tillam produced the most extra-large and total marketable tomatoes. There was no difference in tomato production among alternatives in 1999. During 2000, tomato production was comparable with methyl bromide and Telone C-17 + Tillam, but soil solarization reduced yields to a level between that of the fumigants and the nontreated control.

In the spring cucumber crop, nutsedge populations varied from year to year, apparently affected by the prolonged drought in Florida from the spring of 2000 to the summer of 2001. The number of nutsedge plants increased greatly from spring 1999 to 2000, but declined in 2001. In the spring of 2000, there was more nutsedge in Telone C-17 + Tillam plots than was present in methyl bromide or solarization plots and there was a trend for this again in spring 2001, although the difference was not significant in 2001.

Root-knot nematode populations were the highest in the nontreated control during the first spring cucumber crop and subsequently declined, possibly due to the effects of the drought. Methyl bromide and Telone C-17 reduced root-knot nematode populations with equal results in all 3 years of spring cucumbers. There was little difference in the numbers of root-knot juveniles recovered from any of the treatments in the third year of the study. This is a significant finding for those growers producing more than a single crop on the same plastic.

Cucumber production declined in the nontreated control plots each year, but remained fairly constant with methyl bromide and Telone C-17 + Tillam treatments. Yield fluctuated significantly with soil solarization, ranging from the lowest producer in 1999 to comparable to the fumigants in 2000, and then dropping back to a point between fumigants and the nontreated control.

Alternative Chemicals for Strawberry

Eight small research plot trials at research centers of the University of Florida were conducted to test the efficacy of alternative chemicals. Untreated controls represented the worst overall treatment for strawberry crop yield compared to methyl bromide/chloropicrin, with yields reduced 28 percent. Soil solarization resulted in 21 percent less yield than the methyl bromide/chloropicrin standard. Combination treatments of fumigants, such as metam sodium and Telone C-35 with soil solarization

generally resulted in yield response intermediate between that of the untreated control and methyl bromide/chloropicrin. Application of metam sodium (75 gallons/acre) as a prebedded soil spray, which was incorporated via rotovation, resulted in relative crop yields that were, on average, 8.3 percent less than those with methyl bromide/chloropicrin. Metam sodum, in combination with 1,3-D (Telone) generally improved overall pest control efficacy and crop yield response compared to metam sodium alone and to the methyl bromide/chloropicrin standard treatment. Although not registered for food crop use in the U.S., Basamid (400 pounds/acre) produced relative strawberry yields nearly comparable to that of methyl bromide/ chloropicrin.

In-row, plant bed applications of Telone C-17 (35 gallons/acre) produced yields that were 8.9 percent less than methyl bromide, and 14.1 percent less than Telone C-35 in-row treatment. Strawberry yields obtained with broadcast applications of Telone C-35 were, on average, 4 percent less than yields obtained with methyl bromide. "Highest relative yields were produced with Telone C-35 applied in-row at the time of bedding. This treatment resulted in strawberry yields that were 5.2 percent higher, on average, than methyl bromide and chloropcrin combined," says Noling. Chloropicrin (350 pounds/acre) alone, applied in-row at the time of bed formation, also produced high yields, averaging 2.4 percent higher than that of the standard methyl bromide chloropicrin treatment.

Herbicide Testing

The use of herbicides, other than between rows of mulched-covered beds, has not been required for weed control in Florida vegetable cropping systems that used methyl bromide soil fumigation. Previous research in Florida has demonstrated that none of the alternative fumigants under evaluation are as effective as methyl bromide for weed control, which would mandate the use of separately applied fumigants, per the report. Both preemergent and postemergent herbicides will be needed for weed control in the post-methyl bromide era of crop production in Florida.

Small-plot field studies were conducted from 1998 to 2001 to evaluate various herbicides for crop tolerance and yield performance, and for weed control efficacy in strawberry, tomato, pepper, and watermelon.

Overall, the small-plot herbicide tolerance and efficacy studies have demonstrated that plant growth can be severely retarded—and crop yield significantly reduced—in response to preplant, preemergence, or postemergence herbicide use. "The timing, rates, and methods of herbicide application could all be important factors contributing to phytotoxic crop response and weed control efficacy. It was also evident from these studies that significant interactions between alternative fumigants and tank mix combinations of herbicides can occur and contribute to significant detrimental impacts to plant growth, development, and yield," says Noling. "As in previous studies, this work has also shown that tank mix applications of various herbicides will also likely be required to effectively broaden the spectrum of weed control to the near equivalence of methyl bromide."

At press time, there are currently no efforts underway to get registration for uses of Tillam mentioned in this article. In some of these studies, Tillam is a critical component of the pest and weed control program.

Economic Analysis

A North American fresh-vegetable economic model was developed to evaluate the impacts of the methyl bromide ban on U.S. producers of fresh vegetables. The model is best characterized as a full-season, spatial-equilibrium model encompassing all crops that use methyl bromide as a preplant fumigant. Also included in the model are those crops that are competitive with crops that use methyl bromide. All of the major U.S. vegetable production areas are represented in the model, including two separate regions of Mexico. Florida was spatially separated into four major producing areas including south (Dade), east coast (Palm Beach), southwest (Immokalee), and west central (Ruskin, Plant City). Impacts to Florida double-cropping systems were also estimated within the model. Expected yield impacts following the use of best alternatives to methyl bromide were defined by summaries of previous field research conducted in Florida, as well as by survey summaries of best guestimates provided by University of Florida research scientists. Based on these estimates, a yield loss range of 5 to 30 percent of the average crop yield obtained with methyl bromide was embodied and evaluated as the low-to-high impact scenarios within the North American model.

The loss of methyl bromide, according to model analysis, will have significant impacts on producers and consumers of crops that currently rely on the soil fumigant. Methyl bromide allows the U.S. to remain competitive with Mexico, which relies upon the labor intensive, but relatively less expensive option, of hiring workers to pull weeds from planting beds. Overall, total Florida tomato production is predicted to decrease 2.4 percent, and total shipping point revenues are predicted to decrease $68.1 million. Mexican-

produced tomatoes are expected to gain significant market share with shipping point revenues increasing by $51.5 million. Total U.S. strawberry production is expected to decrease by 35.3 percent, with wholesale price increasing by 9.4 percent and Mexico gaining a minimum of 10 percent market share. Overall summary of model output indicates that if low impacts are realized (5 to 10 percent yield loss), then shipping point revenue losses of $179.5 million in Florida and $143.7 million in California can be expected.

Overview and Future Considerations

Regardless of alternative chemical or application method, these studies show that pest control efficacy for all the fumigant alternatives is generally a little less than that of methyl bromide and more highly dependent upon uniform delivery and distribution. "Unlike methyl bromide, prevailing soil and climactic conditions before and after fumigant application are much more important determinants of efficacy and crop response with alternative chemicals," says Noling. "It is also apparent that growers can cause significant crop response variability through inappropriate land preparation or substandard application procedures." USDA/ARS-funded research has helped identify and further define optimal conditions and procedures required to maximize performance of Telone products, chloropicrin, and other fumigants and herbicides. "However, the culmination of this research has also demonstrated that satisfactory yield responses probably can't be consistently achieved in every field or in every season as equivalent to that of methyl bromide," says Noling. "As a result, growers must learn to expect some disease, some loss, and recognize that some inconsistency is unavoidable. The biggest continuing challenge facing the scientific community in Florida is developing and improving alternatives, which further minimize the 5 to 10 percent impacts on yield for each of the methyl bromide-dependent crops."

Root Knot Nematode Problems in Flower Crops

In Florida, many of the commercially produced cut flowers and bedding plants are grown directly in the ground. This method exposes plants to soil-borne pests and pathogens. Many of the flowers and bedding plants are susceptible to plant-parasitic nematodes, particularly root-knot nematodes (*Meloidogyne* spp.). Snapdragon (*Antirrhinum majus*), lisianthus (*Eustoma grandiflorum*), sunflower (*Helianthus* spp.), and gladiolus (*Gladiolus* spp.) are among those cut flowers particularly susceptible to this soil-borne microscopic worm. Bedding plants most susceptible to root-knot nematodes are coleus (*Coleus blumei*), impatiens (*Impatiens* spp.), celosia (*Celosia argentea*), and snapdragon.

Robert McSorley and K.H. Wang, from the Department of Entomology and Nematology at the University of Florida in Gainesville, are investigating methods for managing nematodes during the flower producers' long growing season. A long growing season may provide excellent opportunity for buildup of nematode populations. Commercial growers may maintain some crops from September to May, with multiple plantings and/or harvests at the same site. In a commercial planting of lisianthus at Sunshine State Carnations farm near Stuart, Florida, fumigated in late July 2001, root-knot nematode populations increased from zero in October, to 18/100 cm^3 soil on February 26, 2002, and to 385/100 cm^3 soil on April 11, 2002. "Despite the eventual recovery of root-knot nematode populations (at 8.5 months after treatment), fumigation with methyl bromide was effective in maintaining low (18/100 cm^3 soil) population levels for 7 months," says McSorley.

In a second study, fumigant treatments were applied on August 21, 2002: methyl bromide (98 percent) + chloropicrin (2 percent) combination mix (450 pounds/acre); metam sodium (75 gallons/acre) + chloropicrin combination mix (150 pounds/acre); and metam sodium (75 pounds/acre). Results were compared to an untreated control. Treatments were replicated four times in a randomized design. Snapdragons were planted on September 30 and October 23. Weed counts, plant heights, and soil samples for nematodes were collected from the experiment at various times.

Weed counts were taken on October 8 and November 14, 2002. There appeared to be a strong effect of fumigants on weeds, but no significant differences among the three fumigant treatments. "The results showed no statistically significant difference between methyl bromide and either metam sodium + chloropicrin or metam sodium alone," says McSorley. Total weed counts on October 8 were 1.25 per 25-foot row for the methyl bromide + chloropicrin treatment, 1.50 for the metam sodium + chloropicrin treatment, and 0.50 for metam sodium. The untreated control had 16.25 weeds per 25-foot row. On November 14, the methyl bromide + chloropicrin treatment had 4.75 weeds per 25-foot row; metam sodium + chloropicrin had 3.75 weeds per row; and the metam sodium treatment had 2.00 weeds per row. The untreated control had 37 weeds per 25-foot row.

Nematode counts were taken on October 9, 2002, November 14, 2002, January 15, 2003, and February 19, 2003. There were some significant effects of fumigants on nematodes, but stubby-root nematodes had recovered in all plots by January. Stubby-root nematodes can be difficult to control by fumigation, but they are not the major nematode pest of flower crops. Control of root-knot nematodes was not significant, though there was a tendency toward higher numbers in untreated control plots. On October 9, there were no root-knot nematodes in the fumigated soil, and 13.2 nematodes/100 cm^3 soil in the untreated control. On November 14, none of the fumigation treatments exhibited any root-knot nematodes, while the untreated control had 0.2 nematodes/100 cm^3 of soil. On January 15, the methyl bromide-treated soil had 0.2 root-knot nematodes/100 cm^3 soil; the metam sodium + chloropicrin-treated soil and the metam sodium-treated soil still had no root-knot nematodes; and the untreated control had 11.9 root-knot nematodes/100 cm^3 soil. On February 19, there were, again, no root-knot nematodes in any of the fumigated soils, but there were 9.8 nematodes/100 cm^3 soil in the untreated control.

Plant heights of two cultivars, Pot Ivory and Pot Pink, were measured on December 5, 2002, January, 15, 2003, and February 19, 2003. According to McSorley, control plants showed some stunting in comparison with the other treatments, especially early in the season. "The effect on plant growth was probably due to weeds early in the season. The grower removed weeds once data counts were made, so effects on plant performance were probably not as severe as they could have been," says McSorley.

Olie Nissen, of the family-run Sunshine State Carnations, collaborated with McSorley and was enthusiastic about the results. "I was pleased with the results, but the costs are high. I will go with either Basamid or one of the other, less-expensive fumigants and accept the losses," says Nissen.

Table 1. Effect of soil fumigation on plant heights of two snapdragon cultivars planted on October 23, 2002.

Treatment	Plant height (cm) Dec. 5	Jan. 15	Feb. 19
	Cultivar: Pot Ivory		
Methyl bromide + CP	13.8 b	55.1 a	93.1 ab
Metam sodium + CP	15.7 b	59.0 a	95.1 a
Metam sodium	19.2 a	61.6 a	89.1 b
Control	10.4 c	54.6 a	94.5 a
	Cultivar: Pot Pink		
Methyl bromide + CP	15.5 a	47.0 a	78.7 a
Metam sodium + CP	15.5 a	42.0 ab	75.4 a
Metam sodium	14.6 a	37.6 b	74.5 a
Control	9.3 b	41.4 b	63.6 b

Data are means of 10 plant measurements. Means in columns for each cultivar followed by the same letter are not different (P<0.05) according to Duncan's multiple range test.
CP = chloropicrin.

Dow AgroSciences Develops Software for ProFume

ProFume (Dow AgroSciences LLC), or sulfuryl fluoride, is considered to be a promising methyl bromide replacement for postharvest pest control. Although ProFume is not yet registered or for sale, the EPA registration for this product has been underway for over 2 years. The substance, under the trade name Vikane gas fumigant, has been used for over 40 years as a structural fumigant to eliminate wood-eating termites and wood-boring beetles. Dow AgroSciences has developed a unique software program to accompany its fumigation product, ProFume, upon its successful EPA registration.

"The ProFume Fumiguide software will allow fumigators to conduct Precision Fumigations—defined as optimizing fumigant use to maximize efficiency and minimize risk. Such an approach provides an overall benefit to the fumigation industry by demonstrating good product stewardship," says Brian Schneider, Dow AgroSciences' ProFume biology development leader.

Sulfuryl fluoride has proved to be very effective against active life stages of postharvest pests, according to research conducted by APHIS National Science Program Leader J. Larry Zettler of the Center for Plant Health Science and Technology in Raleigh, NC. However, sulfuryl fluoride requires a higher dosage for egg stages than for post-embryonic life stages (larvae, pupae, and adults).

"Fumigators in the past didn't have clear parameters for conducting precision fumigations. A certain amount of guesswork and assumption regarding the amount of fumigant to use was involved," says Schneider.

Currently, the methyl bromide label provides target dosage ranges and exposure times for commodities and fumigation conditions. For example, wheat fumigation options range from using 2 to 9 pounds of methyl bromide per 1,000 cubic feet for an exposure time of 4 to 24 hours.

The ProFume Fumiguide software will allow the fumigator to calculate the target dosage based on all the pertinent variables; that is, pest, life stage, temperature, and exposure time. The target dosage, half-loss time (a measure of gas confinement), exposure period, and structure volume are then used to determine how much fumigant is needed for the job. "This would allow each fumigator to precisely match the dosage to the job, reducing wasted fumigant and assuring control of the target pest," says Schneider.

Dosages will not be specified on the label for ProFume since the accompanying Fumiguide will prescribe the target dosage and amount of fumigant to use for each job. The Fumiguide will provide versatility by calculating dosages and designing introduction plans by entire structures, that is, flour mills, or by sections of structures. Fumigators can prepare fumigation plans in advance and make adjustments on-site. For instance, a specialty flour mill may have the option to provide more time for fumigations to be conducted. By extending the exposure period, fumigant costs can be reduced. On the other hand, a large miller may not have this time flexibility, so the fumigator and miller can use the ProFume Fumiguide to consider optimizing the fumigation by increasing temperature or improving sealing. The ProFume Fumiguide allows the fumigator and customer to optimize the fumigation plan for each job conducted because no two fumigations are the same.

As fumigation monitoring data is entered, the ProFume Fumiguide calculates the dosage achieved and the actual half-loss time. The program also predicts dosage outcome and updates dosage instructions as the job progresses. Recommendations for adding fumigant and/or extending the exposure period are also provided in order to achieve the target dosage and control the pest. If the fumigation is going as planned, it will provide that information also.

The ProFume Fumiguide software is designed for a Microsoft Windows-based personal computer and will work on either a laptop or desktop platform. Units of measure will be metric or English. The software allows the fumigator to keep a file of each fumigation job, as well as prepare reports and graphs of completed jobs. The fumigator can also send and receive files from other ProFume Fumiguide users.

Technical Report

Quarantine Application of Bio-Generated Atmospheres for Control of the Large Narcissus Fly

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The large narcissus fly *Merodon eques* F. attacks narcissus bulbs and also bulbs of other geophytes. This species has not been recorded in the USA; and is therefore included within quarantine requirements that demand total mortality prior to export to the USA (Donahaye et al. 1997). Fumigation with methyl bromide (MB) has been used to eliminate narcissus fly infestation in flower bulbs due to its rapid killing time (4 hours). However, MB is also known to cause damage to the bulbs. Therefore, our initial trials were aimed at reducing the MB dosage so as to minimize phytotoxicity and to stabilize concentrations. These trials were carried out in flexible plastic chambers that replaced the rigid fumigation chambers (rooms) previously used.

In experimental procedures, Navarro et al. (1997) found that there was an extremely rapid increase in CO_2 due to the respiration of the newly harvested bulbs. This procedure also revealed the significant toxic effect of CO_2 during treatment and the possibility of using it alone as a control measure. By this time the limitations on MB fumigations were already being defined in meetings of the Montreal Protocol (United Nations Environment Programme 1998) and required the growers to find a permanent non-chemical solution that would also be economical and easy to implement in the field. Consequently, in our laboratory, we studied three treatments of modified atmospheres: high CO_2 concentration (95 percent), vacuum (low pressure of about 50 mm Hg), and storage under hermetic conditions alone. The results showed that the time needed to achieve a 99 percent mortality of fly maggots was about 24 h for the first two treatments and 34 h under hermetic conditions alone. More work is needed to determine the exposure time of Probit 9 for the acceptability of the method to control quarantine pests. Although high CO_2 and vacuum treatments provided a shorter treatment time than storage under hermetic conditions alone, the possibility of obtaining a bio-generated modified atmosphere utilizing the bulb respiration was too tempting to ignore and we adopted this approach.

For the pilot commercial trials conducted in Israel, we applied the

vacuum-hermetic fumigation (V-HF) process used in a newly developed transportable PITS Tunnel (patent-applied Pesticide-free Integrated Transportation and Storage) that is specially designed for rapid machine loading and unloading (Villers 2001). It has two main components: a sealed chamber and a supporting light metal frame. This system consists of an 18.75 m^3 sleeve-shaped chamber made of flexible liner sheeting that can hold vacuum or modified atmospheric gas compositions, with a front opening that is sealed by an air-tight zipper. The supporting portable light metal-frame can be assembled in the designated location and used to hold the chamber in shape for easy loading and unloading of the commodity.

The bulbs were placed in the PITS Tunnel on their original shipping pallets using a forklift. Each pallet was loaded 8 rows high, 5 crates in each row (40 crates totaling approximately 400 kg). In each trial three pallets were arranged inside the PITS Tunnel to evaluate the effectiveness of each treatment. In addition to the three pallets of sorted bulbs, three crates of bulbs infested with fly maggots at sorting were placed at the bottom center and top rows of the crates. In each of these locations a data logger recorded the temperature and humidity. The system was then sealed for 48 h. To minimize space, a slight vacuum of 10 Pa (0.007 mm Hg below ambient) was applied using a hand-held household vacuum cleaner to adhere the PITS Tunnel liner to the crates.

Under these hermetically sealed conditions, there was a rapid depletion of O_2 to 0.1 percent within 18 h, while the CO_2 concentration increased to 21 percent. The temperatures in the chamber ranged from 28 °C to 30 °C, although under the top liner it reached 34 °C at midday. Ambient temperatures outside the chamber ranged from 22 °C at night up to 34 °C at midday. The humidity in the chamber rose steadily from 60 percent to 84 percent relative humidity, while under the top liner it reached 100 percent within 18 h. The ambient humidity changed from 54 percent at midday to 92 percent relative humidity at night.

After treatment in the PITS Tunnel, the three crates of infested bulbs, as well as three samples of non-infested bulbs from crates at the bottom, center and top rows of the pallets, and control, non-treated bulbs were collected. All treated bulbs were examined for live maggots by the researchers, as well as by the Israeli Plant Protection Service inspectors. The results of examining each bulb in the 3 crates of treated infested bulbs revealed 100 percent mortality in all 3 treatments. The treated non-infested bulbs were evaluated at the end of each treatment and bulbs from all pallets passed the requirement needed for export approval. Samples of non-infested treated bulbs and control bulbs were planted in a greenhouse to ensure that there were no phytotoxic effects and to evaluate the quality of the narcissus bulbs. In all cases, no phytotoxic effects were observed and the quality of the treated bulbs was as good as the control bulbs.

In addition to the specific benefits of the V-HF process as an MB alternative for quarantine fumigation of narcissus bulbs, the benefits are several: absence of pesticide residues, reduced safety risk when compared to fumigation, and environmental safety. The PITS Tunnel is transportable and can be assembled by a three-man team. The main drawback to this treatment is the longer exposure time needed compared to MB fumigation. This environmentally friendly method to control quarantine insect pests is applicable to other commodities and is also safe for the operator and the environment.

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